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EFFECT OF ELECTRON IRRADIATION ON SOME PROPERTIES OF THE ECHO II LAMINATE

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SUMMARY

Samples of the Echo II laminate, composed of 0.35-mil-thick plastic with 0.18-mil-thick aluminum glued on both sides, were irradiated with electrons with nominal energies of 0.075, 0.15, 0.26, 0.41, 0.66, 0.92, and 1.20 Mev. Incident fluxes up to 2×10^{13} electrons/cm^2/sec were used. The relative percent changes in the modulus of elasticity, ultimate strength, percent elongation at break, burst strength, hardness, and weight per square centimeter were used as measures of damage. The changes in these properties are given as a function of flux, electron energy, and total integrated flux. The results show that the plastic substrate receives the primary damage. The aluminum outer coating was affected only at very high total integrated fluxes and then primarily because of outgassing within the laminate.

INTRODUCTION

Some months after the orbit of the Echo I balloon it appeared from both optical and radar observation that the balloon had become somewhat wrinkled, presumably because of the loss of the inflation gasses. The next passive communication satellite, the 135-foot-diameter Echo II balloon, will have a much stiffer skin so that, it is hoped, the balloon will remain smooth and spherical after the initial inflation pressure is lost. The Echo II skin is made of 0.35-mil-thick plastic with 0.18-mil-thick aluminum glued to either side. Both outer aluminum surfaces are given a temperature-control coating of an amorphous compound consisting mainly of chromium and aluminum phosphates.

The high-altitude thermonuclear explosion of July 9, 1962, produced a new and intense belt of electron radiation at the orbital altitudes planned for Echo II (refs. 1, 2, 3, and 4). As a result of this new belt, Echo II may be exposed to an electron flux as great as 10^7 electrons/cm^2/sec. Since the satellite will have to remain for many years in this environment, the present study was initiated in order to study the effect of such long exposure to geomagnetically trapped electron radiation on the physical properties of the Echo II laminate.

Samples of the Echo II laminate were irradiated with electrons of energies between 75 Kev and 1.2 Mev, with total integrated fluxes from 10^{14} to 10^{17} electrons/cm^2. The properties studied in order to determine the effects of the irradiation were modulus of elasticity, ultimate strength, percent elongation, burst strength, hardness, and weight per square centimeter. The changes in these properties are presented herein as functions of flux, total integrated flux, and kinetic energy.

A preliminary paper on certain portions of this study has been previously published as reference 5.

SYMBOLS AND ABBREVIATIONS

e	electron
E	modulus of elasticity, used herein as the secant modulus at 1-percent elongation, lb/in.^{2}
Kev	thousand electron volts
Mev	million electron volts
s_{ult}	ultimate tensile stress
μa	microamperes

TESTS AND EQUIPMENT

Apparatus

The accelerator used in these tests was a constant-voltage cascaded-rectifier type. This accelerator is capable of producing fluxes of monoenergetic electrons up to 10 milliamperes $(6.25 \times 10^{16}$ e/cm^2/sec$)$, with kinetic energies variable between 75 Kev and 1.2 Mev. The experimental test setup is shown in figures 1 and 2. The beam enters from the accelerator and passes down the beam tube through a scanning magnet which scans it vertically in the scan horn at approximately 10 cycles per second. The beam then passes into air through a blower-cooled, 2-mil-thick titanium window. The laminate sample, which consists of 0.35-mil-thick poly[ethylene terephthalate] plastic with 0.18-mil-thick aluminum glued to either side, is suspended in the beam at a distance of approximately 6 inches from the titanium window and approximately $1\frac{1}{2}$ inches in front of a solid aluminum support plate.

The kinetic energy of the electrons at the location of the laminate was determined by measuring the absorption of the electrons in aluminum foil (ref. 6, pp. 608-609) at the location of the test samples. It will be noted that this measurement was made after the electrons had already passed through a titanium foil with a weight of 23.4 mg/cm^2. In passing through the titanium foil the electrons had not only suffered a degradation in energy, but the beam was no longer completely monoenergetic. At energies above about 300 Kev, the energy loss was small (about 50 Kev), and the resulting energy spread was probably also small. At lesser energies, the energy loss was greater, and the resulting energy spread was probably correspondingly greater. In any event, the method used to measure energy would yield an energy close to the peak energy in the actual distribution at the sample location.

The uniformity of the beam intensity was determined through the use of cobalt glass dosimetry. An area of approximately 3 by 15 inches was found to be uniform to within ±5 percent.

Test Procedures

The physical properties studied were:

(1) Modulus of elasticity (secant modulus at 1-percent elongation)

(2) Tensile strength

(3) Percent elongation at break

(4) Burst strength

(5) Hardness

(6) Weight per square centimeter

The first three properties were measured simultaneously on a tensile tester with a pulling speed of 2 inches per minute and a gage length of 2 inches.

Burst strength is the average obtained with two samples in a burst-strength tester. The surface hardness was measured by a micro-hardness tester with a 50-gram loading. The weight per square centimeter was determined by measuring the weight of 1/3-square-centimeter samples on an electrobalance. The measured values of all six properties for the unirradiated laminate are shown in table I.

RESULTS AND DISCUSSION

Effect of Flux

Since the flux in these tests is necessarily higher than that in space, the initial portion of this investigation was a study of effects due to various fluxes upon the foils. Figure 3 gives the results of this study. The use of two different total integrated flux values was necessitated by time considerations. The low flux levels would take much too long to obtain 10^{16} e/cm^2, and the high flux levels would deliver 10^{15} e/cm^2 in too short a time to measure accurately. Figure 3(b) shows significant change above a flux of 1.12 μa/cm^2 or 7×10^{12} e/cm^2/sec. For fluxes below this value there is no change in the amount of damage measured.

The decreased damage at the higher fluxes is possibly associated with the heating of the laminate. It will be noted that the sample is subjected to two major sources of heat during these tests. First is the heating due to the loss of kinetic energy of the electrons in passing through the laminate. Secondly, the sample is subject to radiant heating from the hot titanium window of the accelerator and the aluminum backing plate which stopped the electrons from the accelerator.

The effect of flux on the temperature of bare iron-constantan thermocouples at the sample location is shown in figure 4. Since the thermocouple bead would absorb more electron energy per unit surface area (cooling area) than would the laminate, the temperature-increase curve shown in figure 4 is considered to represent an upper limit for the laminate. The flux of 1.12 μa/cm^2 that was used in all the subsequent tests would then produce a temperature rise in the laminate less than 50° F.

It should be noted, however, that some of the reduction of damage may possibly be a true flux effect rather than an effect of increased temperature.

Effect of Total Integrated Flux

Figure 5 shows the change in the physical properties as a function of integrated flux at various electron energies. The most notable effect is a rapid degradation of the percent elongation, which is reduced by about 25 percent even at the lowest flux used in these tests. This reduction in elongation is reflected, at somewhat higher integrated fluxes, in the early and brittle failure of the samples in both the burst-strength and tensile tests. The modulus of elasticity, hardness, and weight per square centimeter were essentially unchanged.

It will be observed that for figures 5(a) and 5(e), there are no points for modulus of elasticity and hardness for an integrated flux above 3×10^{16} e/cm^2. The modulus of elasticity as used throughout this report is the secant modulus at 1-percent elongation. At an integrated flux above 3×10^{16} e/cm^2 the percent elongation was, in general, less than 1 percent and, consequently, the modulus could not be measured. The degree of surface damage at these doses was such that a clean indentation would not be obtained with the micro-hardness tester. These surface effects will be discussed more fully in a subsequent part of this report.

The fact that the properties studied herein fall into two groups, one of which shows major changes and the other essentially none, is of interest since it indicates which portion of the laminate has sustained the major portion of damage. It is to be noted that in the tests of the unirradiated and lightly irradiated laminates, the aluminum failed long before the plastic in both the burst and tensile tests. At the highest integrated fluxes, there must be some damage to the aluminum since the aluminum by itself should be able to carry about 15 percent of the initial tensile strength, whereas, at the highest integrated fluxes, the irradiated specimen generally retained much less than 15 percent of its tensile strength. This additional loss, however, is probably not a direct radiation effect; this point will be discussed subsequently in this paper. Thus, except perhaps for the highest integrated fluxes, these properties indicate almost solely the condition of the plastic. On the other hand, the modulus of elasticity, which is measured in the initial portion of the stress-strain curve, and the hardness, which is measured by indenting the aluminum surface, are primarily indicative of the condition of the aluminum. Further, it will be noted that the aluminum surface protects the plastic from either weight loss due to outgassing or weight gain from oxidation reactions. Thus, any weight change would necessarily imply a loss of integrity of the aluminum foil. The conclusion, therefore, is that the plastic has sustained essentially all the radiation damage and the aluminum was essentially unaffected by radiation.

Blistering

A notable effect of very high integrated fluxes is the blistered appearance of the surface. A photograph of the surface after an integrated flux of 10^{17} e/cm^2 is shown in figure 6. This photograph is typical of the test results at all energies. The blisters are probably due to outgassing of the material in the laminate. The effect is not simply due to heating, since heating in an oven for several days at 200° F, which is considered to be as high or higher than the temperature attained during the exposure, does not produce the same effect.

It has not yet been ascertained whether the gas originated in the glue, the plastic, or both. The initial suspicion, however, points to the glue as a major factor since many of the bubbles are more sharply defined on one face than on the opposite face of the laminate. This asymmetry might indicate that the bubbles are not within the plastic but are rather at the interface between the plastic and the aluminum.

As was mentioned previously, there is some change to the ultimate strength of the aluminum foil itself. The integrated flux is considered to be too small for this change to be a true radiation effect. It would appear that the blistering due to outgassing, rather than irradiation itself, is responsible for the damage to the aluminum.

Effect of Kinetic Energy

The energies of the electrons in space range from quite low values to several Mev. The relative effectiveness of electrons of different energies may be seen in figure 7, where the percent reduction in the physical properties is shown as a function of electron energy for several integrated fluxes. This figure is essentially a cross plot of the data previously presented in figure 5; however, it also contains some additional data.

In general, figure 7 shows more damage for energies on the order of 0.2 Mev than it does for energies of 1.2 Mev. This result is reasonable and can be easily explained. Below 1 Mev the linear energy transfer of electrons (the energy deposited per unit length) increases rapidly as the energy decreases (ref. 6, pp. 622-625). Thus, the lower energy electrons deposit more energy in the laminate than do the higher energy electrons and consequently cause more damage until the point where the electrons no longer completely traverse the plastic, after which the damage decreases as the energy decreases.

At the lowest integrated flux, figure 7(a), the variation of damage with energy is only slightly apparent because of the low total damage. The variation is more evident at the higher integrated flux, figures 7(b) and 7(c), where the damage is greater. The effect of kinetic energy is no longer apparent at the highest integrated flux, figure 7(d), where even the highest energy electrons (least linear energy transfer) are sufficient to completely destroy the pertinent physical properties.

Effect on Echo II Satellite

Electron damage to the Echo II satellite laminate may be estimated by using a known spectrum of trapped electrons to weight the results presented herein. This calculation has not been made because it is apparent that the damage will not be significant. Because of leaks already present in the skin and additional leaks created by meteoroids, the internal inflation pressure (and the corresponding skin tension) is not expected to be maintained very long, hardly as much as a few months. The total integrated exposure for this period will be of the order of 10^{14} e/cm^2, which will not greatly affect the mechanical properties of the skin. Even after exposure to 10^{17} e/cm^2 the skin strength will be adequate for the small remaining stresses, such as those due to the surrounding atmosphere, solar pressure, and gravity gradient.

CONCLUDING REMARKS

The results of a study on the effects of electron irradiation on some physical properties of the Echo II laminate, composed of 0.35-mil-thick plastic and 0.18-mil-thick aluminum, indicate that:

1. The primary effect of electron irradiation is an increased brittleness of the plastic, resulting, at high integrated fluxes, in the early and brittle failure of the laminate in tensile and burst-strength tests.

2. There is no essential change in the modulus of elasticity, hardness, or weight per square centimeter.

3. Severe surface blistering occurs at the highest total integrated flux used in this study (above 10^{17} e/cm^2). This blistering results in physical damage to the aluminum foil.

4. The damage due to electron irradiation increases as the energy of the electrons decreases, presumably until the point where electrons no longer completely traverse the plastic layer.

5. The effects of flux on the degree of damage are negligible until fluxes at least two or three orders of magnitude higher than those in space are reached.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 15, 1964.

REFERENCES

1. Hess, Wilmot N.: The Artificial Radiation Belt Made on July 9, 1962. NASA TN D-1687, 1963.

2. O'Brien, Brian J.: Radiation Belts. Scientific American, vol. 208, no. 5, May 1963, pp. 84-96.

3. Hess, Wilmot N.: Man-Made Radiation Belts. Int. Sci. and Technology, no. 21, Sept. 1963, pp. 40-48.

4. Foelsche, Trutz: Current Estimates of Radiation Doses in Space. NASA TN D-1267, 1962.

5. James, Thomas G.: Effect of Electron Irradiation on the Mechanical Properties of a Composite Foil for Inflatable Satellites. Proc. Symposium on the Protection Against Radiation Hazards in Space. TID-7652, Book 1, U.S. Atomic Energy Commission, Nov. 1962, pp. 260-268.

6. Evans, Robley D.: The Atomic Nucleus. McGraw-Hill Book Co., Inc., c.1955.

TABLE I

AVERAGE PHYSICAL PROPERTIES OF UNIRRADIATED SAMPLES

Modulus of elasticity, lb/in.^{2}	1,217,000
Tensile strength, lb/in.^{2}	16,800
Elongation at failure, percent of 2-inch gage length	24
Burst strength, lb/in.^{2}	23.6
Hardness (Vickers)	20.0
Weight, mg/cm^2	4.01

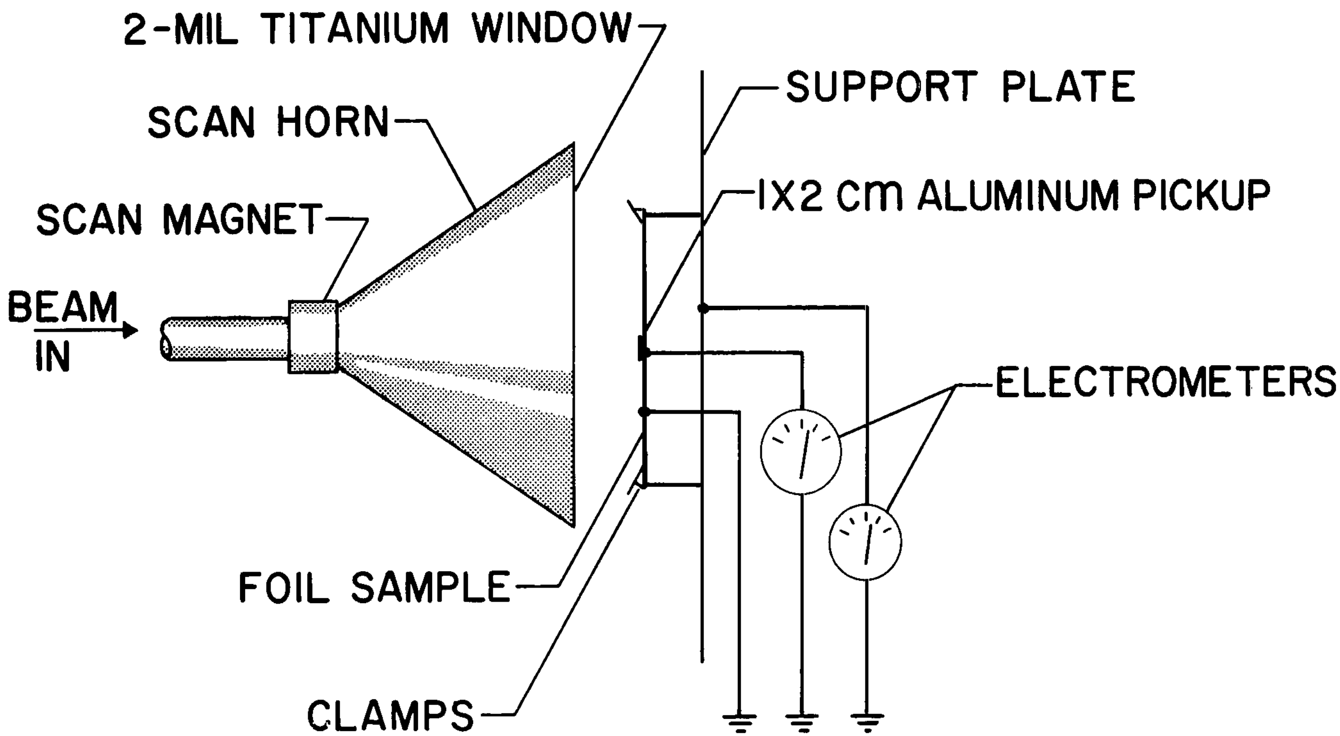

Figure 1.- Sketch of experimental arrangement for Echo II laminate irradiation tests.

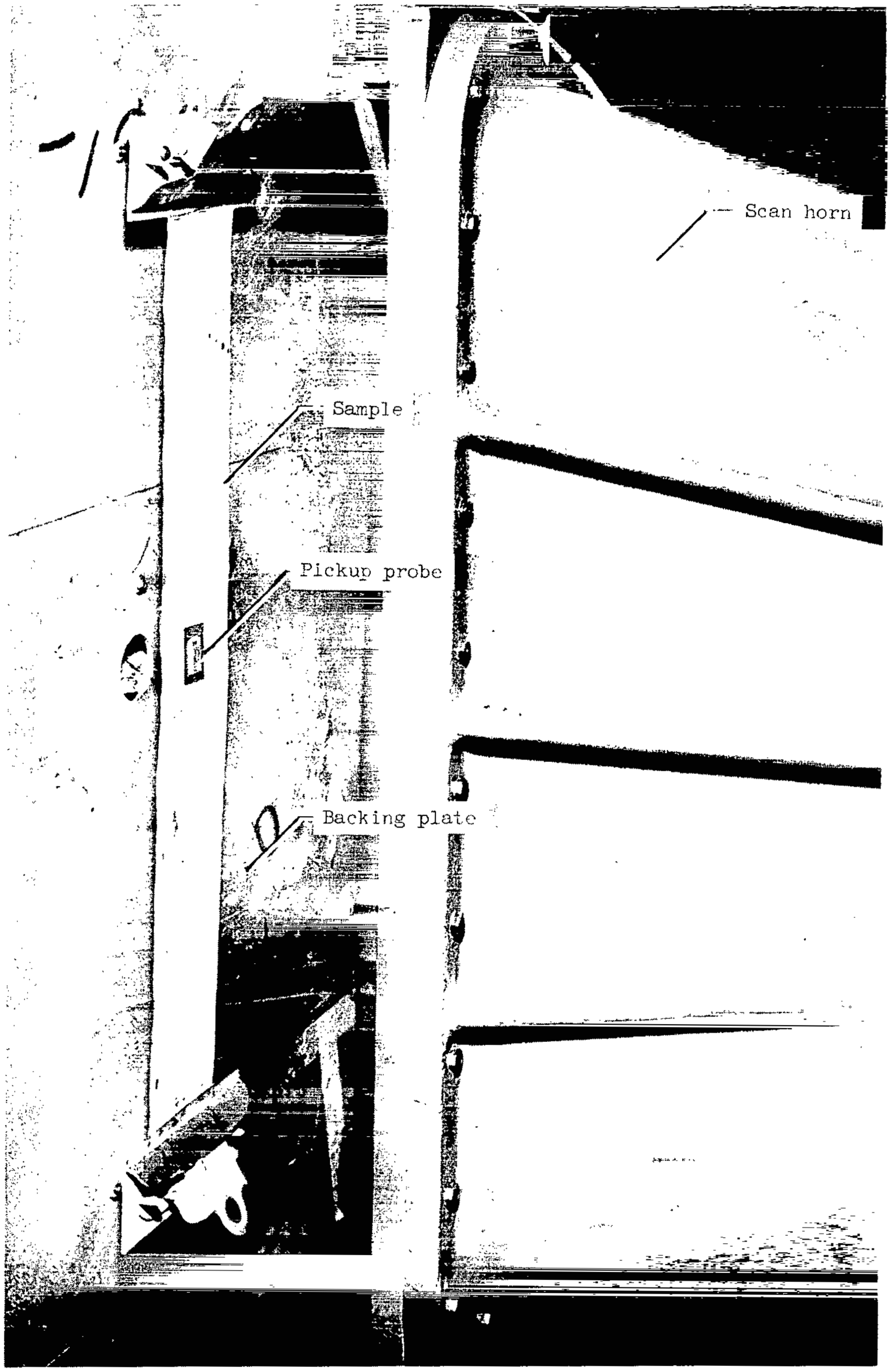

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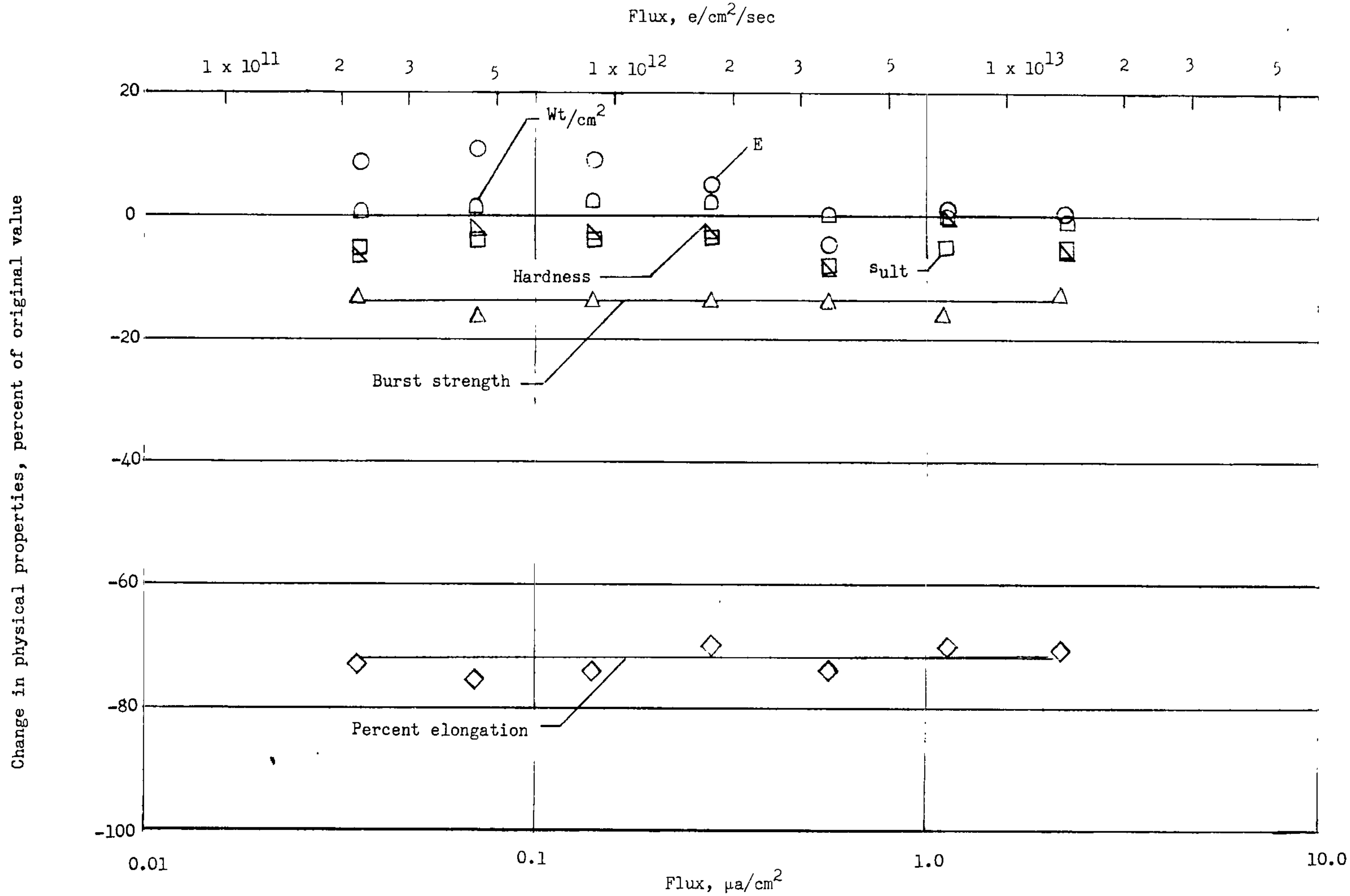
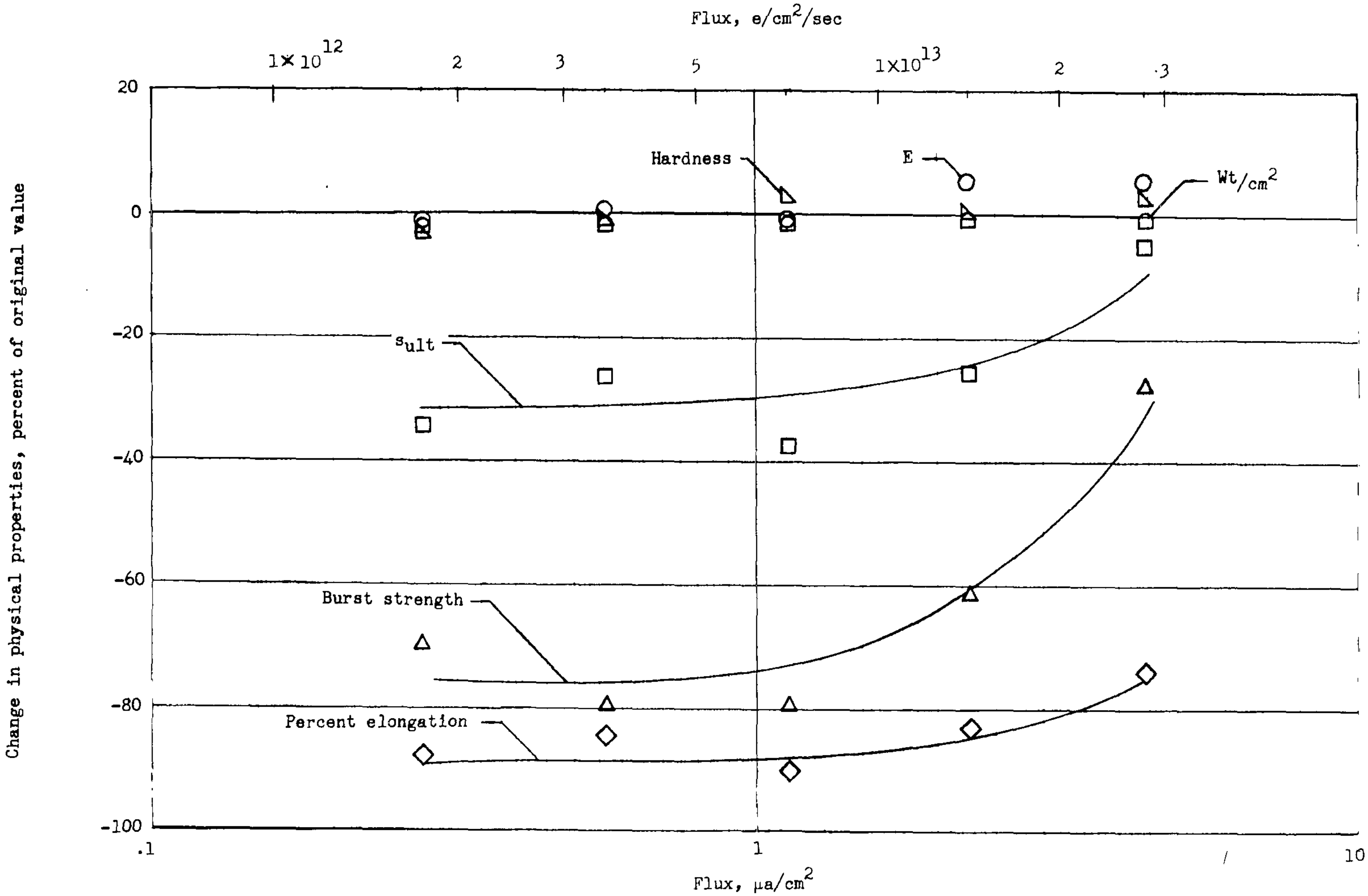
Figure 2.- Photograph of a sample of Echo II laminate mounted for test.



(a) Integrated flux of 3.2×10^{15} e/cm^2.

Figure 3.- Effect of flux on the physical properties of Echo II foil after irradiation by 1.2 Mev electrons.



(b) Integrated flux of 3.2×10^{16} e/cm^2.

Figure 3.- Concluded.

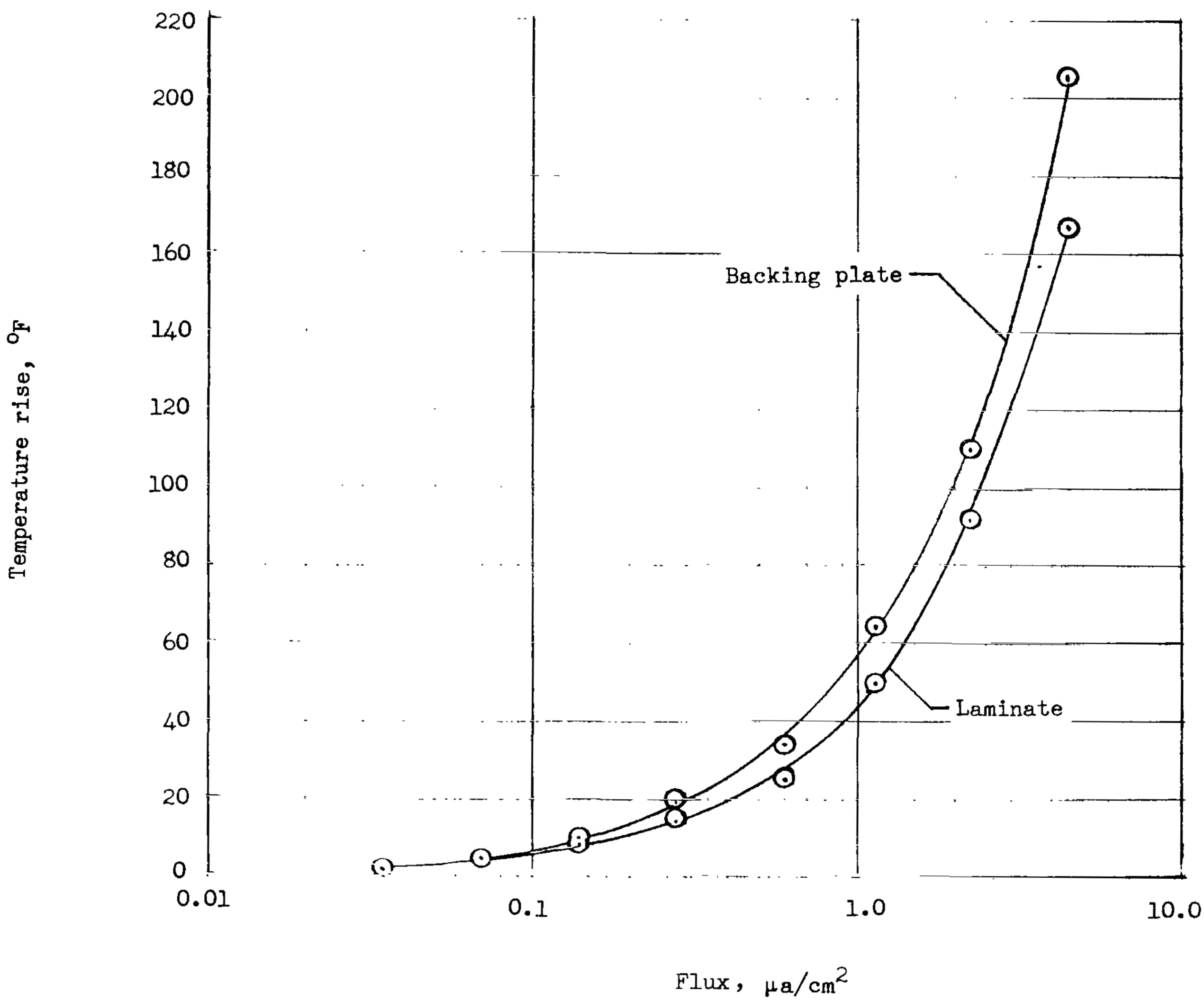
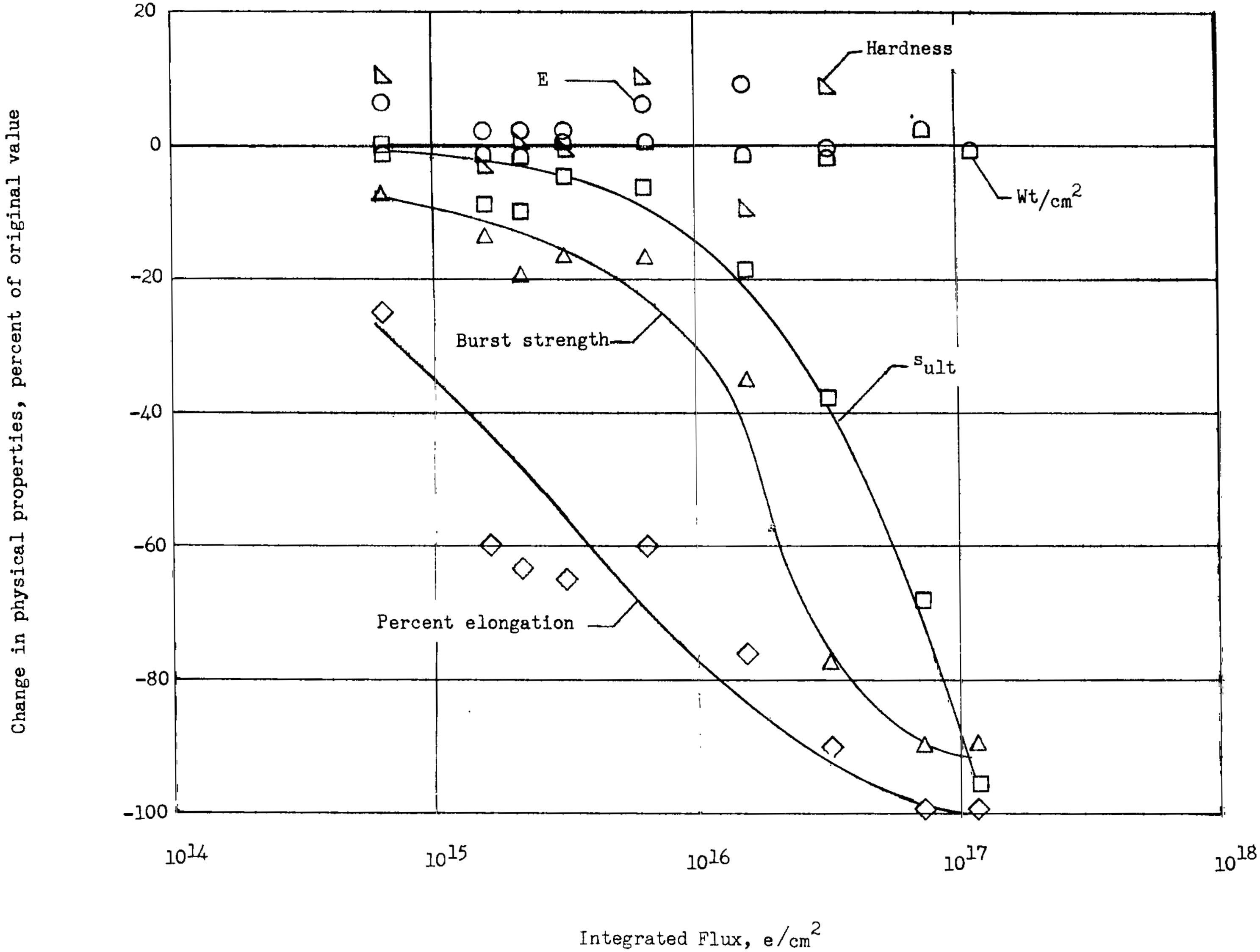
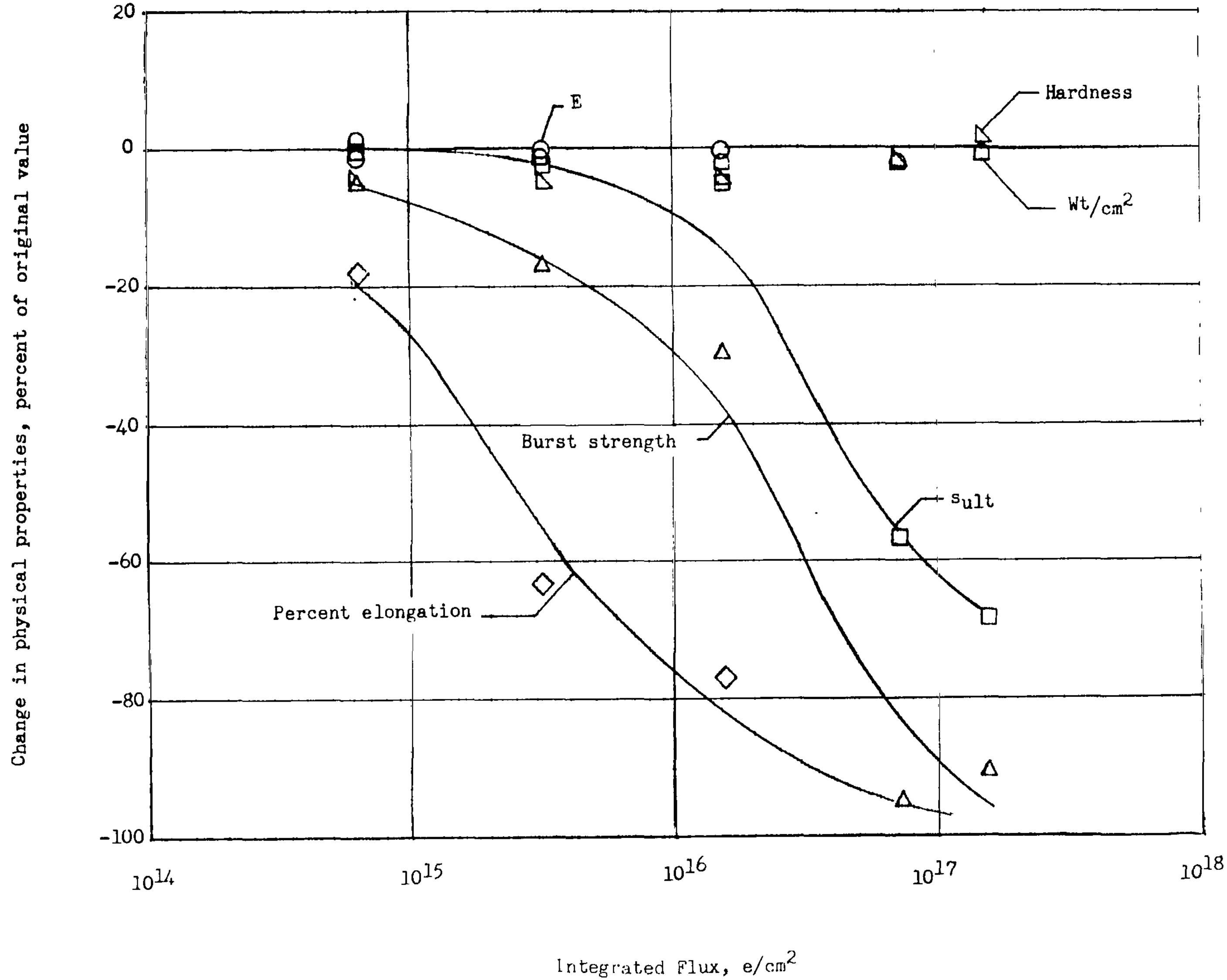


Figure 4.- Temperature measurements on laminate and backing plate as a function of flux for an electron energy of 1.2 Mev.



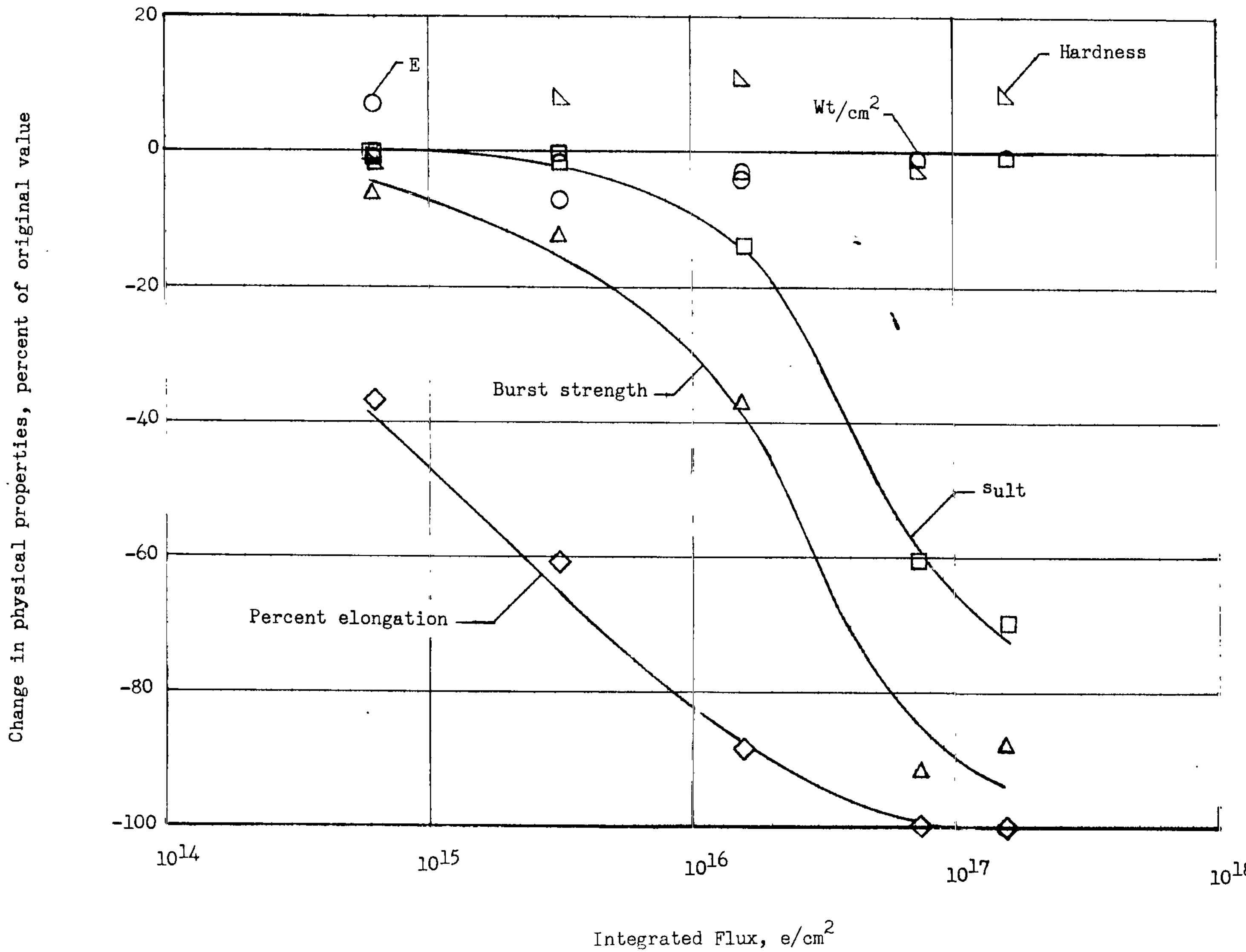
(a) Electron energy, 1.2 Mev.

Figure 5.- Effect of integrated flux on the physical properties of the Echo II laminate for several different electron energies; flux is 7×10^{12} e/cm^2/sec.



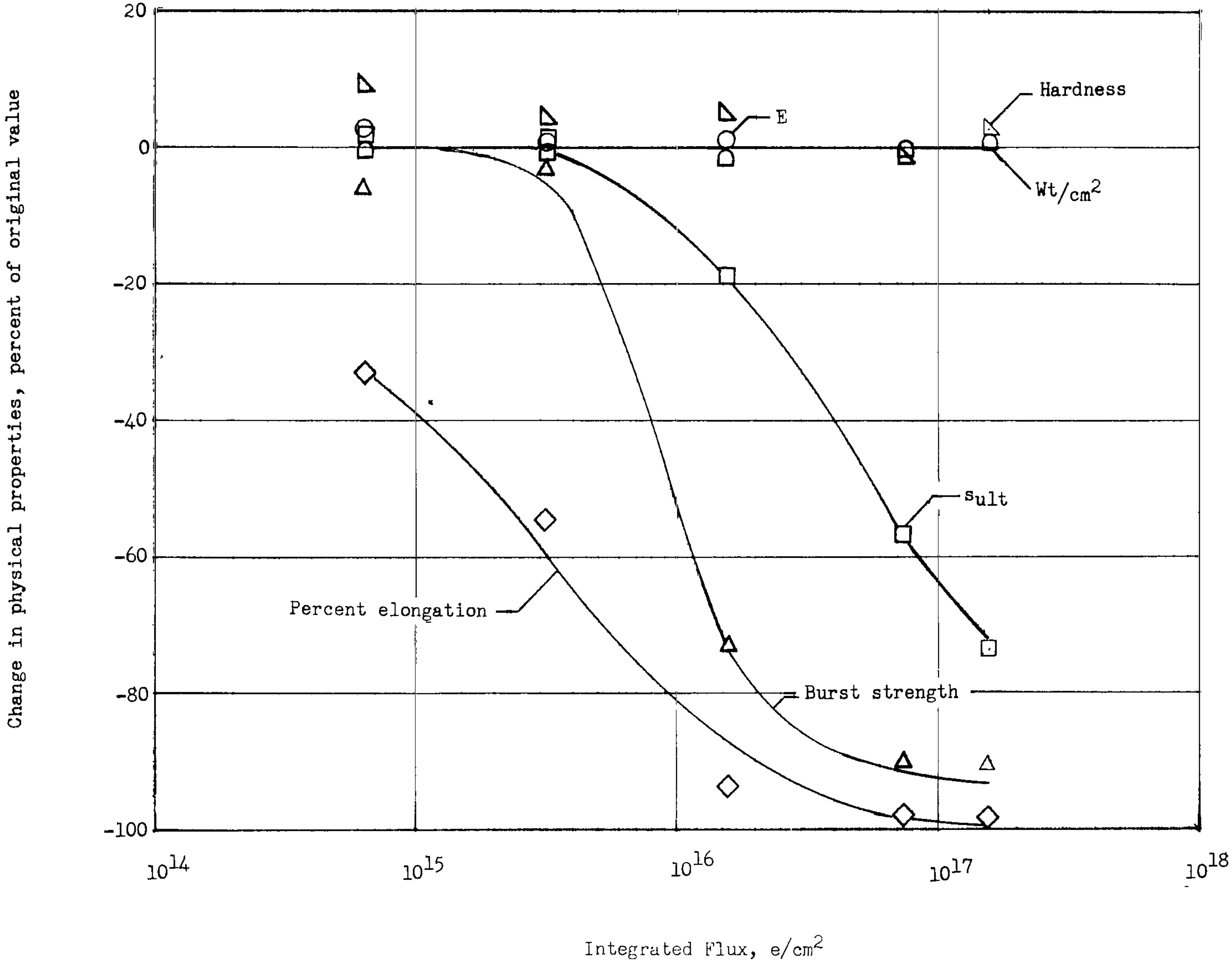
(b) Electron energy, 0.92 Mev.

Figure 5.- Continued.



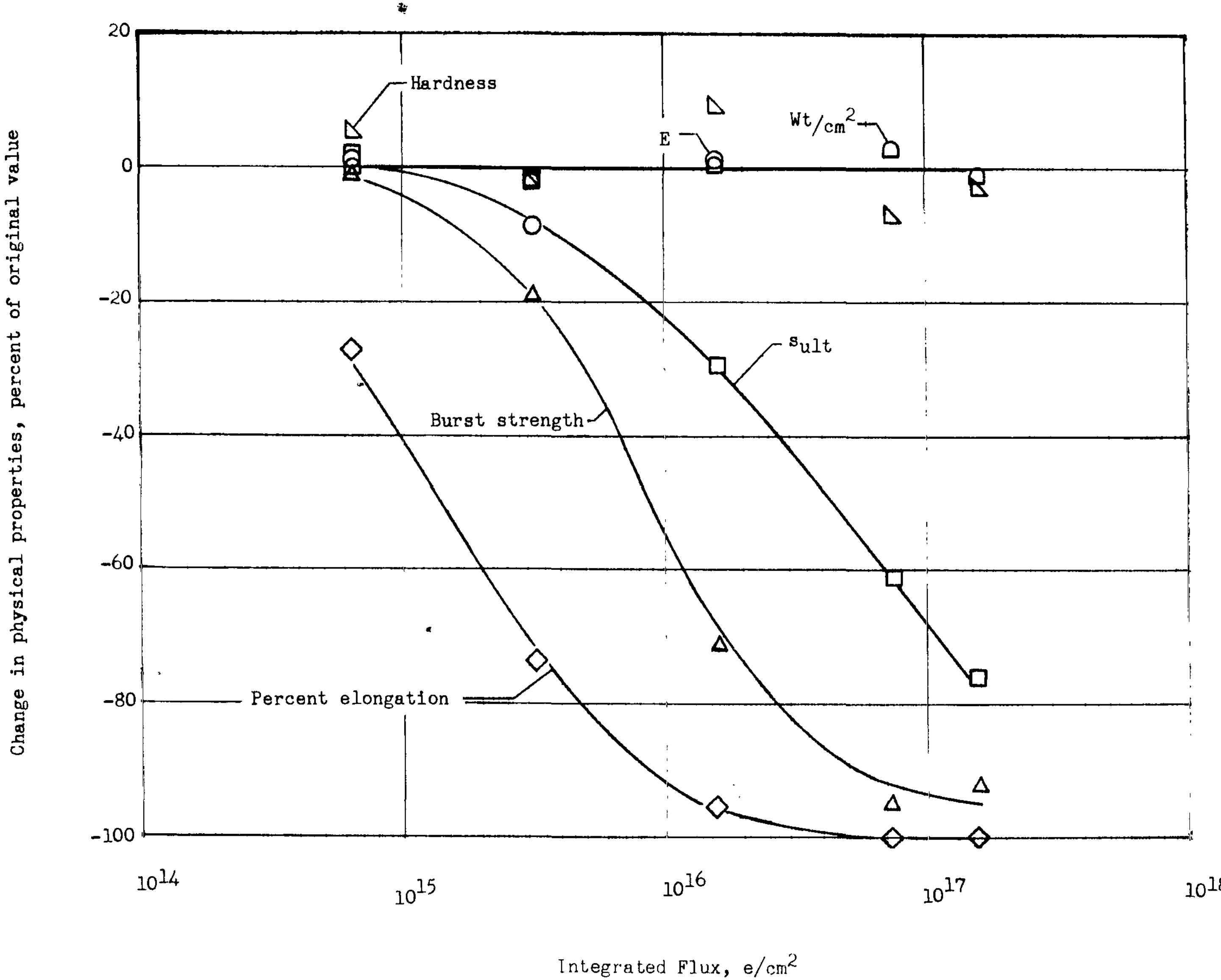
(c) Electron energy, 0.67 Mev.

Figure 5.- Continued.



(d) Electron energy, 0.41 Mev.

Figure 5.- Continued.



(e) Electron energy, 0.15 Mev.

Figure 5.- Concluded.

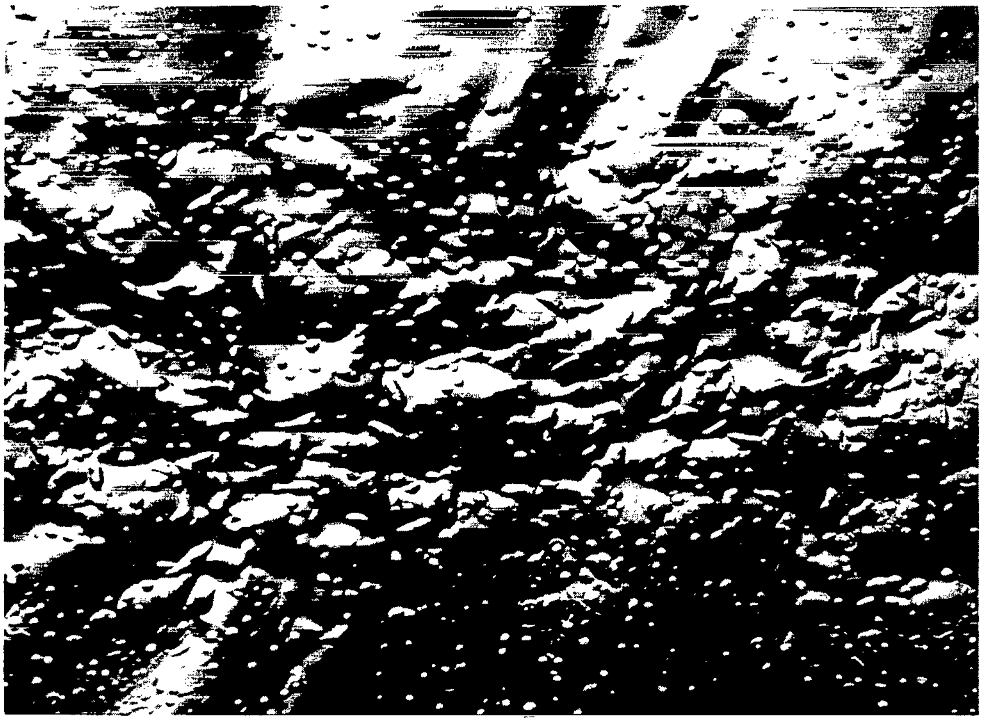


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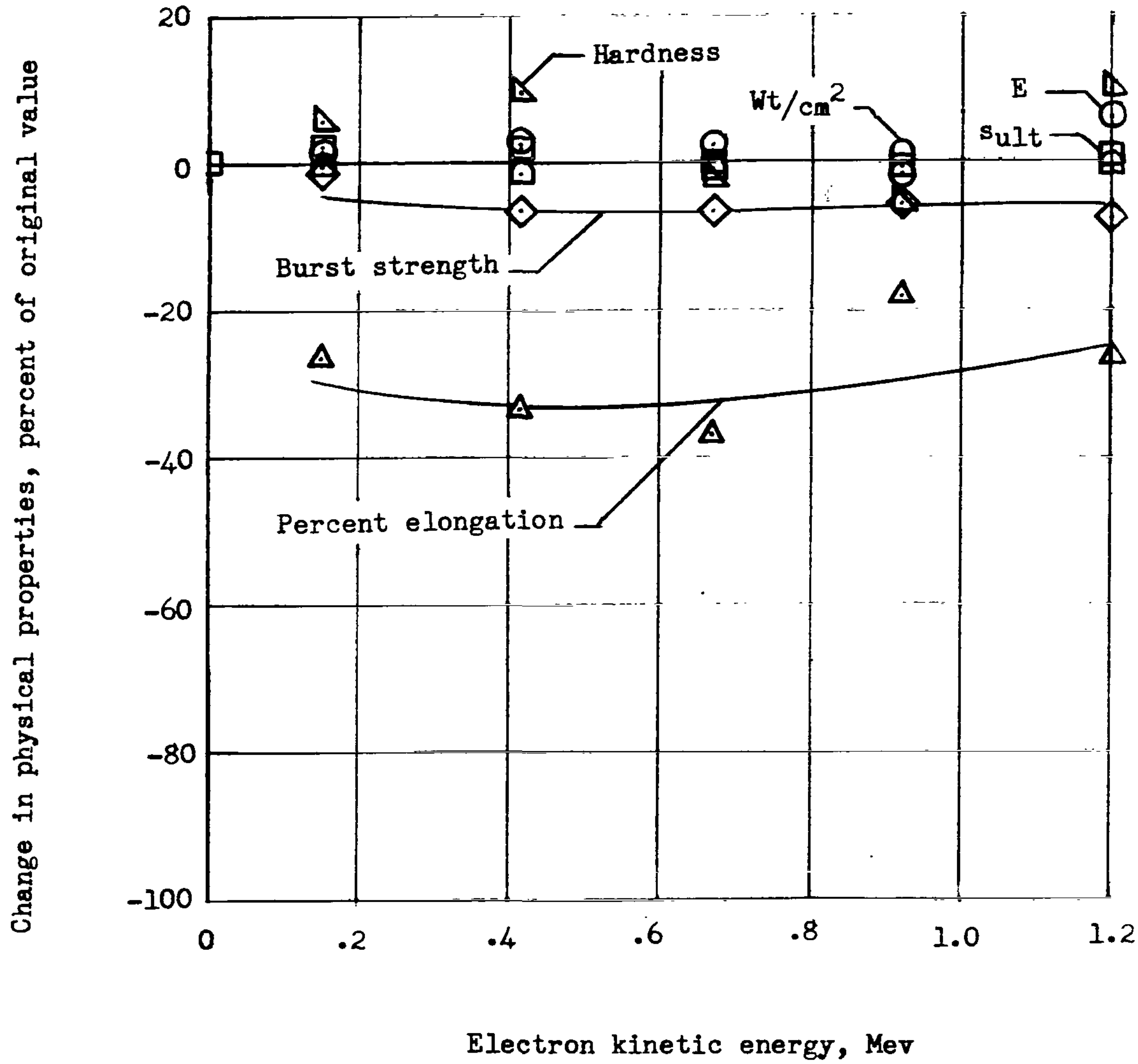
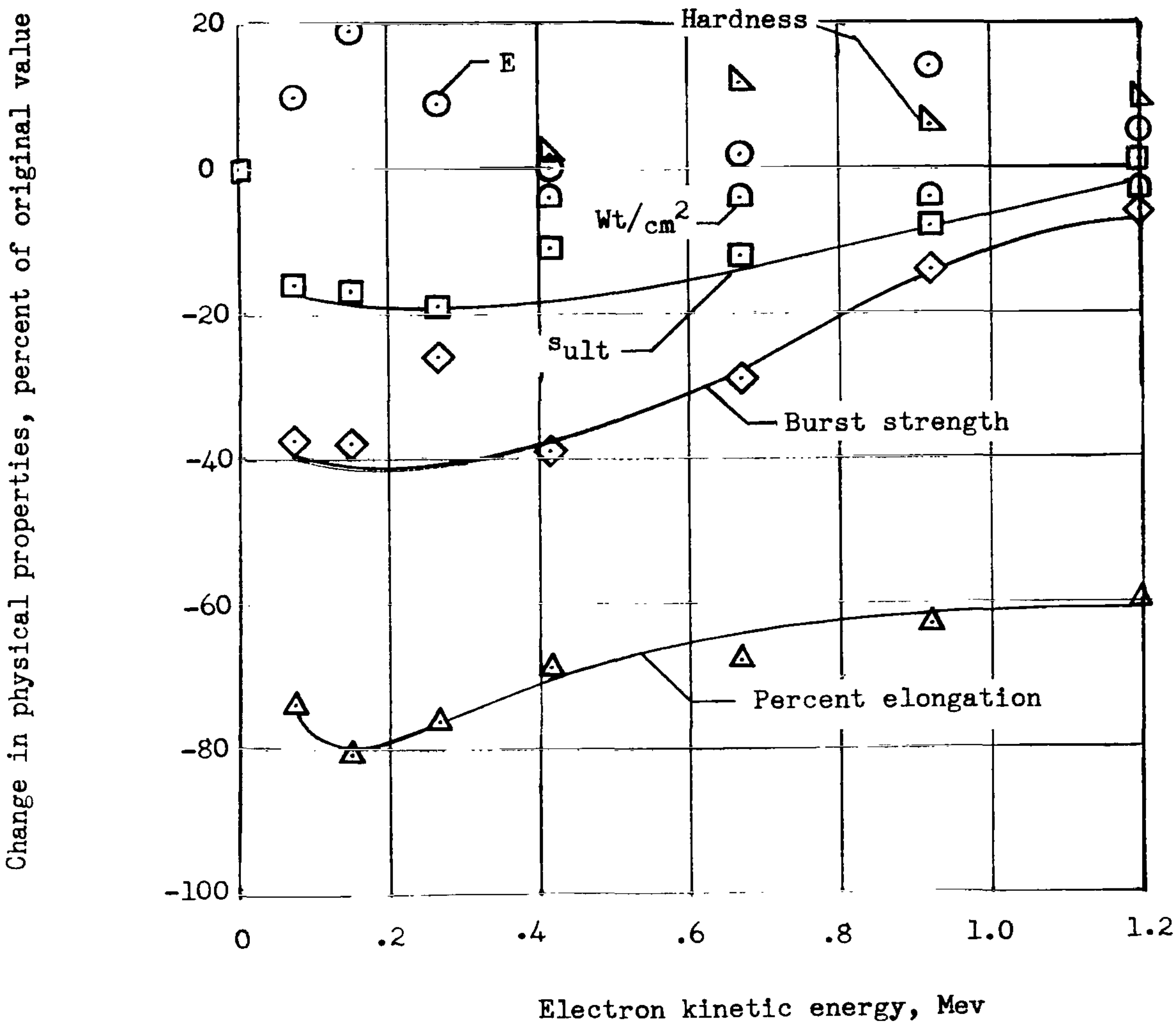
Figure 6.- Blistered appearance of Echo II laminate after exposure to electrons of 0.67 Mev. Integrated flux of 1.6×10^{17} e/cm^2; photograph full scale.



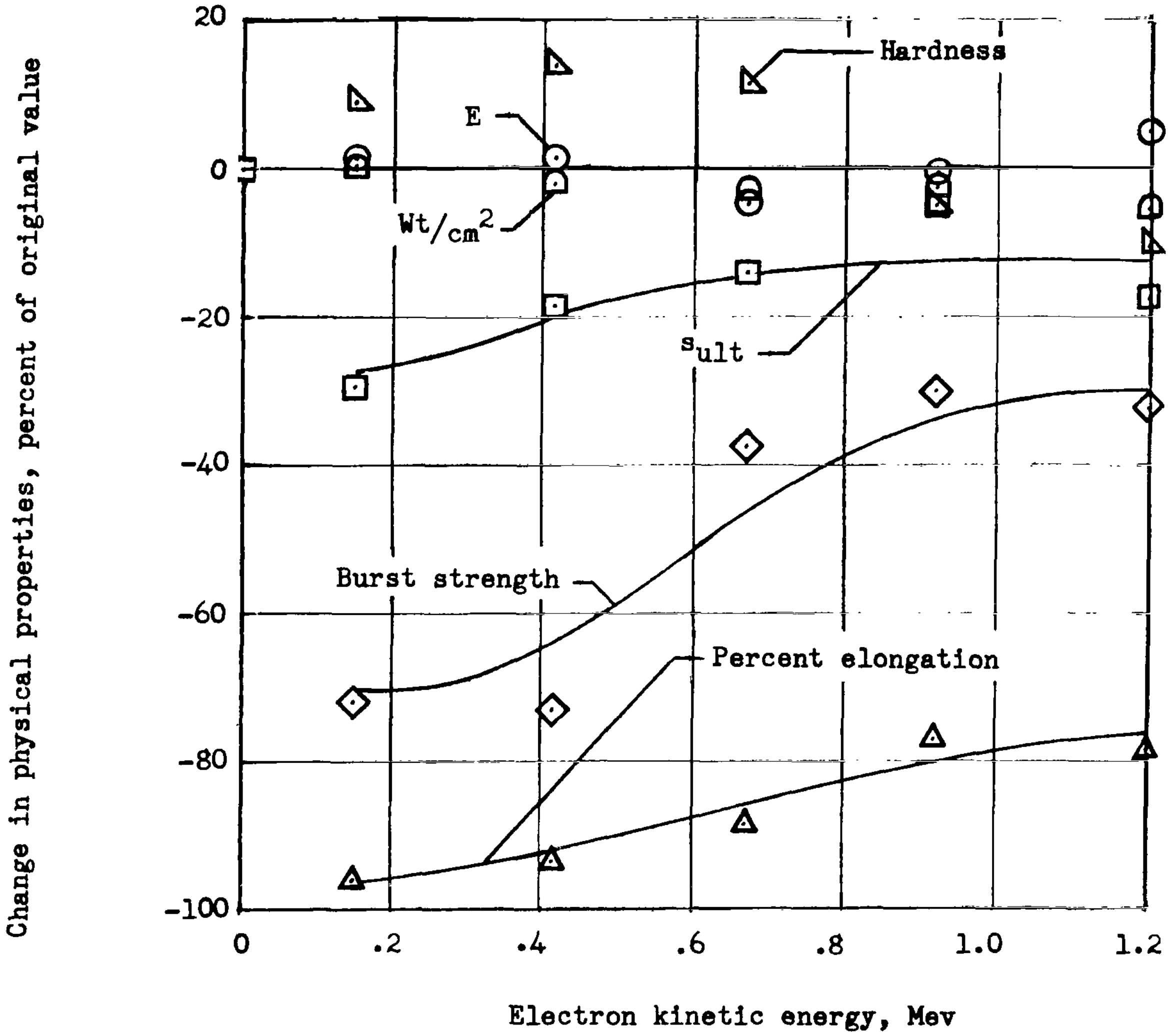
(a) Integrated flux of 6.31×10^{14} e/cm^2.

Figure 7.- Effect of electron kinetic energy on the physical properties of the Echo II laminate for several different integrated fluxes. Flux of 7×10^{12} e/cm^2/sec.



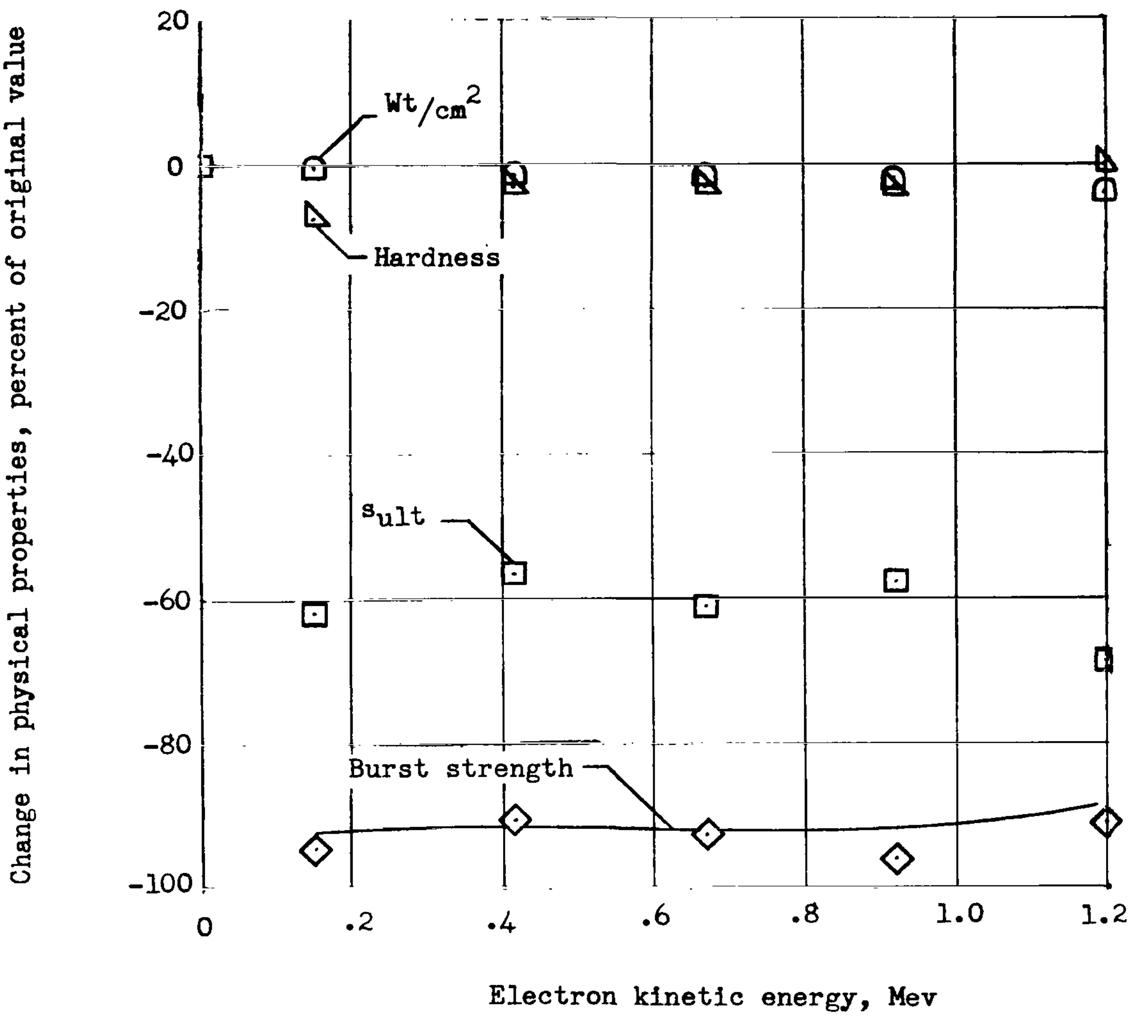
(b) Integrated flux of 6.3×10^{15} e/cm^2.

Figure 7.- Continued.



(c) Integrated flux of 1.6×10^{16} e/cm^2.

Figure 7.- Continued.



(d) Integrated flux of 7.3×10^{16} e/cm^2.

Figure 7.- Concluded.

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